

Featured Article

The Effects of COVID-19 on Fruit and Vegetable Production

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Abstract *COVID-19 has had unprecedented effects on the US economy, in large part because of its effects on workers. Within food and agriculture, these effects pose the greatest threat to the production of labor-intensive commodities – in particular, fruits and vegetables, the production of which tends to require large numbers of workers for harvesting and packing. We econometrically estimate the effects of COVID-19 on fruit and vegetable production as the US agricultural labor supply is adversely affected by this pandemic. The major crop losses include \$16 million in lettuce, \$5 million in apples, and \$4 million in grapes.*

Key words: COVID-19, farm labor, fruit and vegetable production.

JEL codes: Q02, Q11.

Introduction

The outbreak of COVID-19 has affected the US economy in ways that were previously unimaginable, and fears over the epidemic's potential effects on agriculture have been particularly acute given the vital nature of the food supply. As one of the most labor-intensive sectors in agriculture (USDA-ERS 2020), fruit and vegetable production is one of the sectors with the most at stake in light of COVID-19's threats to the farm labor force.¹ The challenges posed by the COVID-19 epidemic threaten an industry that has already been under siege from ongoing labor shortages (Charlton and Taylor 2016; Richards 2018).

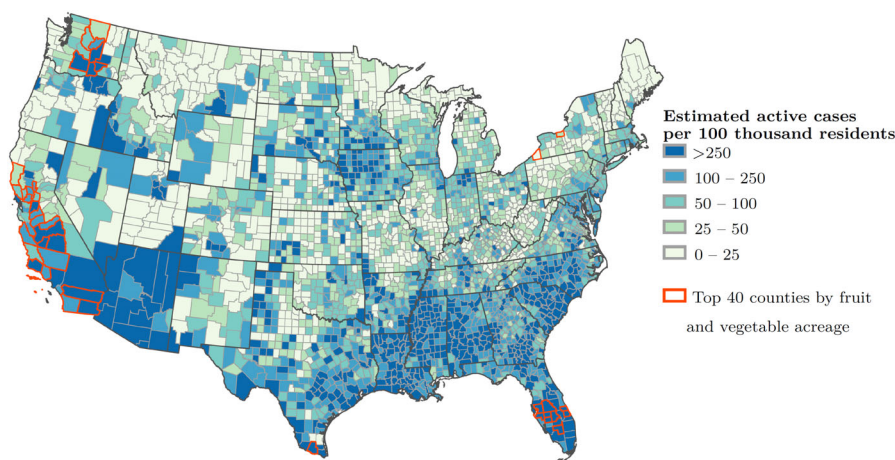
Many of the largest outbreaks of the virus have disproportionately affected farm workers, with the conditions under which many workers live and work, such as close-quarters dormitory-style housing for migrant laborers,²

¹Meatpacking has also endured severe COVID-19 outbreaks.

²With many workers living in garages and sharing a single bathroom, and riding in crowded buses or vans to the field.

Figure 1 Estimated active COVID-19 cases as of June 30th, and top 40 labor-intensive fruit and vegetable producing counties

Notes: Active COVID-19 case rates estimated from Johns Hopkins University (2020) data; fruit and vegetable acreage from USDA-NASS (2020). [Color figure can be viewed at wileyonlinelibrary.com]



contributing to the virus's spread. Such conditions have led to significant and ongoing outbreaks in some of the country's largest fruit- and vegetable-producing regions. Figure 1 illustrates active COVID-19 case rates by county, and also highlights the top 40 fruit- and vegetable-producing counties by bearing acreage. Combined, these 40 counties alone account for nearly 75% of US acreage devoted to labor-intensive fruit and vegetable production (USDA-NASS 2020) and have almost uniformly experienced significant and protracted outbreaks.³

We explore COVID-19's effects on fruit and vegetable production in light of the ongoing and widespread proliferation of COVID-19 in the farm labor force. To accomplish this, we employ detailed county-level data on employment in agriculture, use of nonlabor inputs, and commodity-level production to econometrically estimate the relationship between labor supply and the production of labor-intensive fruits and vegetables. This allows us to consider how production responds to changes in the number of workers that producers can employ. We then use our estimates of this relationship to generate predictions on the likely labor-supply effects of the virus over the course of the 2020 harvest season based on current infection rates, and offer detailed commodity- and region-specific estimates of anticipated losses in fruit and vegetable production.

COVID-19's Effects on Fruit and Vegetable Production

Our analysis of COVID-19's effects on fruit and vegetable production is comprised of two main elements. First, in order to predict the production response to COVID-19-induced disruptions in the farm labor supply, we must estimate the relationship between fruit and vegetable production and labor use, accounting for other inputs such as land, machinery, and chemicals.

³We consider labor-intensive fruits and vegetables, rather than all fruits and vegetables, since the production of commodities that can be readily mechanically harvested – e.g., potatoes, beans, or tart cherries – is less likely to be affected by labor supply issues.

To achieve this, we estimate a county- and commodity-level production function and obtain the output elasticity of labor. Second, based on these estimates of the output elasticity of labor, we calculate the expected reduction in fruit and vegetable production by county as a function of the reduction in the labor supply based on the two alternative scenarios for active COVID-19 case rates described above. This allows us to predict, by county and commodity, the anticipated production losses in labor-intensive fruit and vegetable from the pandemic. To accomplish these tasks, we need to address two data-related issues.

First, the extent of the virus's spread has varied widely across regions (see figure 1). Systematic evidence on the virus's spread in the farm labor force is not yet available, but farm workers are arguably at an elevated risk of contracting the virus. For example, news media accounts describe severe outbreaks among workers in fruit and vegetable production, including outbreaks among 201 workers at a berry farm in Ventura County, California (Rode 2020); 90 cases on a watermelon farm in Alachua County, Florida (Sexton 2020); and 120 workers at an orchard in Okanogan County, Washington (Bernton 2020). With minority communities bearing the brunt of the epidemic (CDC 2020), and given the largely Hispanic composition of the farm labor force, farm workers are at an elevated risk relative to the rest of the population. The wide variation in demographic and economic conditions across counties, policy responses from state and local governments of differing intensity and duration, and other unexplained factors have led to some regions experiencing widespread outbreaks, and others remaining relatively unscathed (Desmet and Wacziarg 2020). This implies that an analysis that was to only consider state-level or regional outcomes would neglect important geographical variation; we therefore construct our estimates at the county level for the forty-eight contiguous US states.

Second, fruit and vegetable production varies substantially in the degree to which operational practices rely on manual labor. For example, while the harvest of some (but not all) lemons, grapes, and onions can be aided by machinery, commodities such as lettuce and fresh-market cherries are harvested and processed almost entirely by hand. Therefore, the effects of changes in the labor supply will differ from commodity to commodity, even within labor-intensive fruit and vegetable production. We thus break down our estimates across specific products, focusing on the labor-intensive fruits and vegetables for which labor-supply effects are likely to be most pronounced. Table 1 presents the commodities that we consider in this analysis, the total production of which accounted for approximately \$30 billion of value in the 2017 Census of Agriculture.

Our primary data source is NASS and we collect data for 2017, the year of the most recent Census of Agriculture.⁴

Data on county-level production and input use at the commodity level is not generally available aside a handful of cereals and other major crops. However, NASS does report acreage by county and commodity, acreage by state and commodity, and total state-level production by commodity, along with county-level agricultural employment, total expenditures on chemicals and fertilizer, and the asset value of farm equipment, which we use to impute county- and commodity-level production, the number of employed agricultural workers, and nonlabor input use for major labor-intensive commodities.

⁴While use of 2017 data may not be reflective of 2020 economic conditions, production, acreage, and input use do not tend to fluctuate substantially from year to year. To illustrate, the correlation between NASS-reported bearing acreage by county and commodity in 2012 versus 2017 is approximately 0.99.

Table 1 Production Values of Labor-Intensive Fruits and Vegetables for 2017, in Millions of Dollars

Commodity	Value of production	Commodity	Value of production
Apples	3,601.4	Grapefruit	256.9
Artichokes	65.5	Grapes	6,507.8
Asparagus	100.8	Honeydew	94.2
		Melons	
Avocados	392.0	Lemons	763.4
Bell Peppers	625.6	Lettuce	4,235.7
Blueberries	833.5	Onions	1,042.1
Broccoli	925.7	Oranges	1,943.7
Cabbage	431.3	Peaches	599.9
Cantaloupe	296.0	Pears	519.3
Cauliflower	67.3	Plums	114.9
Celery	322.0	Strawberries	2,895.8
Cherries	891.7	Tomatoes	1,678.0
(Sweet)			
Chili Peppers	113.6	Watermelons	594.0
Cucumbers	392.0		
		Total	30,304.1

Source: USDA-NASS (2020).

The quantity of production (in tons) of commodity k in county c in state s is calculated using the formula

$$Y_c^k = \left(\frac{\text{Acreage of commodity } k \text{ in county } c}{\text{Acreage of commodity } k \text{ in state } s} \right) \times Y_s^k. \quad (1)$$

In words, a county's production of a specific commodity is calculated as the proportion of the county's acreage in total state acreage devoted to the commodity multiplied by the total state production of the commodity.

While data on the size of the agricultural labor force is available at the county level, we again must impute commodity-specific values. Based on NASS data on agricultural employment by county, we calculate the amount of labor engaged in the production of commodity k in county c (denoted L_c^k) as

$$L_c^k = \left(\frac{\text{Acreage of commodity } k \text{ in county } c}{\text{Total fruit and vegetable acreage in county } c} \right) \times L_c, \quad (2)$$

where L_c is the number of hired workers (including temporary migrant workers) in county c . That is, the calculated amount of labor employed in the production of a particular commodity, L_c^k , is equal to the acreage share of that commodity in the county's total output of fruits and vegetables, multiplied by the number of farm workers employed in the county.⁵

⁵Implicit in this calculation is the assumption that all, or nearly all, farm workers in fruit- and vegetable-producing regions are employed in fruit and vegetable production. While this could cause us to overstate the number of workers engaged in the production of each commodity in our analysis, it is unlikely that substantial numbers of workers in large fruit- and vegetable-producing regions are engaged in the production of other commodities, such as cereals, livestock, or non-labor-intensive fruits and vegetables, as production

Finally, we must impute the use of nonlabor inputs by county and commodity for inclusion in our production function estimation, as their omission would bias our estimate of the relationship between labor and output. Similar to our calculation for labor, we impute expenditures on chemicals and fertilizer (denoted by C_c^k) and the asset value of farm equipment (denoted by M_c^k) based on acreage-weighted shares of county totals:

$$\begin{aligned} C_c^k &= \left(\frac{\text{Acreage of commodity } k \text{ in county } c}{\text{Total acreage planted in county } c} \right) \times C_c, \text{ and} \\ M_c^k &= \left(\frac{\text{Acreage of commodity } k \text{ in county } c}{\text{Total acreage planted in county } c} \right) \times M_c, \end{aligned} \quad (3)$$

where C_c and M_c represent total county expenditures on chemicals and fertilizer and the asset value of farm equipment, respectively. These calculations differ slightly from that for labor, in that the shares are based on total planted acreage by county. This is because labor is primarily used in fruit and vegetable production, whereas chemicals, fertilizer, and machinery are utilized in the production of non-labor-intensive commodities.

In summary, our estimation will rely on county-level production (Y_c^k , the acreage-weighted share of total state production); county-level acreage by commodity (A_c^k , from NASS); and county-level inputs of labor, chemicals and fertilizer, and machinery (L_c^k , C_c^k , and M_c^k , respectively), each calculated from acreage-weighted shares of their respective county totals.

Estimating the Relationship between Production and Labor

Using the data on production, labor, land, chemicals, and machinery, we estimate the relationship between the production of fruits and vegetables and input use based on the commonly used translog production function.⁶

Output of commodity k in county c as a function of inputs X_i is given by

$$\log Y_c^k = \alpha_0 + \sum_i \beta_i \log X_{ic}^k + \frac{1}{2} \sum_{i,j} \gamma_{ij} \log X_{ic}^k \log X_{jc}^k, \quad (4)$$

with i and j indexing inputs labor, chemicals and fertilizer, land, and machinery.⁷ We enforce the symmetry constraint that $\gamma_{ij} = \gamma_{ji}$ for all i, j . We allow for variable returns to scale in production by enforcing no restrictions on the relationship between the β_i terms.

Of primary interest here are the coefficients on labor, which include the direct effects on output of a change in labor (β_L and γ_{LL}) in addition to terms that reflect the complementarity or substitutability between labor and other inputs (the γ_{iL} and γ_{Lj} terms for i, j = chemicals, land, and machinery). We

of these commodities tends to (i) take place in other, nonfruit-and-vegetable-producing areas, and (ii) rely substantially less on farm labor.

⁶This production function was originally developed by Christensen, Jorgenson, and Lau (1973) and extended by Kim (1992), and (along with its counterpart the translog cost function) has been extensively utilized in the applied economics literature; for example, to investigate input use and efficiency in agriculture (Barnes 2008; Takeshima 2017), to explore industrial energy use (Lin and Xie 2014), and to estimate the determinants of economic growth (Evans, Green, and Murinde 2002).

⁷We enforce the symmetry constraint that $\gamma_{ij} = \gamma_{ji}$ for all i, j . We allow for variable returns to scale in production by enforcing no restrictions on the relationship between the β_i terms.

Table 2 Estimates of Fruit and Vegetable Production Function

	Labor	Chemicals	Land	Machinery
β_i terms	0.281* (0.138)	0.647** (0.247)	0.537*** (0.181)	-0.302 (0.242)
γ_{ij} terms (symmetrical matrix)				
Labor	0.033*** (0.009)	0.026 (0.020)	-0.014 (0.017)	-0.058*** (0.017)
Chemicals		0.011 (0.021)	-0.017 (0.016)	-0.061* (0.033)
Land			-0.007 (0.006)	0.055*** (0.020)
Machinery				0.035** (0.017)

Notes: Number of observations is 899. Robust standard errors clustered by state. Estimation includes commodity and state fixed effects. Asterisks ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

further include state- and commodity-specific fixed effects in estimating equation (4) to control for unobserved underlying differences in the determinants of production across states and commodities.⁸

Estimates of the input coefficients are shown in table 2. Most of the coefficients on the labor-related terms are statistically significant and broadly consistent with theory and intuition. However, because the individual coefficients have no meaningful economic interpretation, we instead direct our focus on the output elasticity of labor, which can be obtained from the estimated coefficients. From the translog function, the output elasticity of labor for each commodity (denoted by $\epsilon_{Y,L}^k$) is calculated as

$$\epsilon_{Y,L}^k = \frac{\partial \log Y_c^k}{\partial \log L_c^k} = \frac{\% \Delta Y_c^k}{\% \Delta L_c^k} = \beta_L + \sum_j \gamma_{Lj} \log \bar{X}_j^k, \quad (5)$$

where \bar{X}_j^k is the average level of input j used in production of commodity k . That is, for a given change in labor, the anticipated percentage change in output will be equal to $\epsilon_{Y,L}^k$, which is equal to the sum of the β_L and γ_{Lj} terms multiplied by the respective (log) levels of each input.

Estimates of the output elasticity of labor for each commodity are reported in table 3. The elasticities range in value from approximately 0.09 for grapes to 0.18 for artichokes. The elasticities are generally lower for commodities such as apples and oranges, whose harvest and processing can sometimes be aided by mechanization, and higher for commodities such as artichokes and avocados, that are less amenable to mechanized production methods.

To obtain the overall effect of a change in labor on production of commodity k in county c , we express equation (5) as

⁸We only include county-commodity observations for which the 2017 bearing acreage is 100 or greater. Such counties account for roughly 97% of the total US acreage of the commodities in our analysis, and omitting counties with lower acreage means that our data primarily reflect commercial production, rather than hobby farmers or U-pick growers. Our results are robust to this cutoff.

Table 3 Estimates of Output Elasticity of Labor by Commodity

Commodity	$\epsilon_{Y,L}^k$	Commodity	$\epsilon_{Y,L}^k$
Apples	0.117	Grapefruit	0.116
Artichokes	0.184	Grapes	0.090
Asparagus	0.139	Honeydew Melons	0.146
Avocados	0.165	Lemons	0.168
Bell Peppers	0.174	Lettuce	0.146
Blueberries	0.121	Onions	0.114
Broccoli	0.144	Oranges	0.113
Cabbage	0.128	Peaches	0.111
Cantaloupe	0.113	Pears	0.148
Cauliflower	0.157	Plums	0.149
Celery	0.163	Strawberries	0.166
Cherries (Sweet)	0.135	Tomatoes	0.116
Chili Peppers	0.118	Watermelons	0.104
Cucumbers	0.112		

$$\% \Delta Y_c^k = \epsilon_{Y,L}^k \times \% \Delta L_c^k. \quad (6)$$

We assume that an infected worker is effectively removed from employment because of quarantine, illness, or death, and that labor shortages cannot be filled in the short run – as most fieldworkers are migrant H-2A or undocumented workers, it is generally infeasible to replace lost workers in short order.

We thus relate $\% \Delta L_c^k$ – the percentage change in labor supply by commodity and county – to active COVID-19 infections by considering two alternate scenarios on the farm labor supply.⁹

Scenario 1 is a conservative scenario in which the infection rate for farm workers is equal to the general population, and thus $\% \Delta L_c^k$ is equal to the (negative) percentage of the general population in county c with active cases (as of June 30).¹⁰

Scenario 2 is an extreme scenario assuming that the incidence of infections among farm workers is four times that in the general population, based on CDC (2020) data reflecting the difference in COVID-19 hospitalization rates for Hispanics versus non-Hispanic whites.

Based on the relationship in equation (6), estimates of $\epsilon_{Y,L}^k$, data on labor and other inputs, and active COVID-19 infection rates, we turn to our primary objective of estimating the effects of COVID-19 on fruit and vegetable production.

⁹The number of active estimated cases by county must be estimated from data on newly reported cases, as data on recoveries is incomplete due to medical privacy laws. We estimate the number of active cases according to the formula provided by the ArcGIS COVID-19 Trends map (Esri 2020): Active Cases = Recent Cases + Severe Cases + Critical Cases, where Recent Cases are all new cases reported in the previous two weeks, Severe Cases are 19% of new cases reported in the previous fifteen to thirty days, and Critical Cases are 5% of new cases reported in the previous thirty-one to fifty-six days.

¹⁰In late June, the number of confirmed new cases in the United States averaged around 35,000 per day (Johns Hopkins University 2020); since then, however, the number of cases has risen considerably. By July and August, between 40,000 and 60,000 cases per day were being reported, and sometimes over 70,000.

Results

We estimate the labor-supply effects of COVID-19 on fruit and vegetable production along three different dimensions: total production losses for each commodity across all states, total production losses for each state across all commodities, and total county-level effects.

Table 4 presents the estimated effects on production by commodity for all states. Not surprisingly, the commodities with the largest values of production stand to lose the most, but regional disparities in the spread of the virus imply that the production of some commodities will be more affected than others. The largest losses are estimated to accrue in lettuce, grape, apple, and orange production, reflecting the large outbreaks that have taken place in the primary locations in which such commodities are produced. Particularly striking is the estimated effect on lettuce production, and the explanation for this finding is straightforward. The overwhelming majority of lettuce in the United States is grown in the counties of Monterey, Imperial, and Santa Barbara, California and Yuma, Arizona, each of which has been affected by severe outbreaks of COVID-19 (with Yuma containing over 1,000 estimated active cases per 100,000 residents as of June 30; Johns Hopkins University 2020). In contrast, commodities with smaller values of production (artichokes, chili peppers, and plums) tend to incur smaller losses. Major vegetable commodities (such as lettuce, onions, and broccoli) and perishable fruits (such as grapes) also experience heavy losses. In total, we estimate over \$12 million in lost production of fruits and vegetables in the conservative scenario, and \$48 million in the extreme scenario. While modest relative to the overall size of the fruit and vegetable sector, these effects on fruit and vegetable production have important implications for consumers as well as downstream food processing industries because of the short supply of fruit and vegetables.

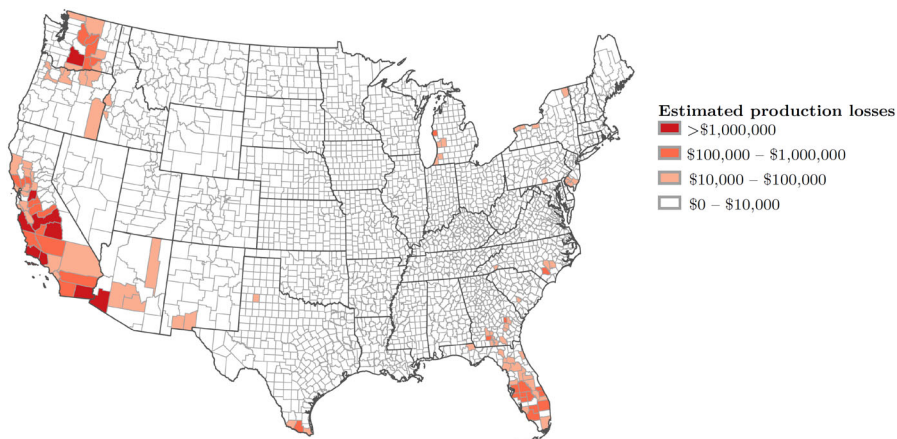
Table 4 Estimated Production Losses by Commodity, in Thousand Dollars

Commodity	Scenario 1	Scenario 2	Commodity	Scenario 1	Scenario 2
Apples	-1,343.6	-5,374.3	Grapefruit	-91.9	-367.8
Artichokes	-21.4	-85.8	Grapes	-1,089.5	-4,357.9
Asparagus	-57.3	-229.1	Honeydew	-31.2	-124.7
			Melons		
Avocados	-109.7	-438.6	Lemons	-449.2	-1,796.7
Bell Peppers	-237.0	-948.2	Lettuce	-3,893.0	-15,572.0
Blueberries	-168.1	-672.6	Onions	-415.0	-1,659.9
Broccoli	-364.7	-1,459.0	Oranges	-817.1	-3,268.5
Cabbage	-159.3	-637.2	Peaches	-117.4	-469.5
Cantaloupe	-141.8	-567.2	Pears	-142.4	-569.5
Cauliflower	-339.3	-1,357.3	Plums	-40.5	-162.1
Celery	-102.6	-410.5	Strawberries	-876.4	-3,505.6
Cherries	-374.1	-1,496.5	Tomatoes	-418.9	-1,675.7
(Sweet)					
Chili Peppers	-16.6	-66.4	Watermelons	-192.6	-770.4
Cucumbers	-64.8	-259.3			
			Total	-12,075.6	-48,302.4

We present the estimated cumulative losses of all commodities at a detailed county level for scenario 2, which illustrates the severity of the losses (figure 2). The graphical representation of the estimates sheds light on two important aspects of our findings. First, while the estimated effects of labor-supply shocks on fruit and vegetable production arising from COVID-19 outbreaks are inherently confined to fruit- and vegetable-producing states, the widespread nature of the outbreak implies that many parts of the country are affected, from the hard-hit West Coast and Southwest, to the Southeast, to scattered fruit- and vegetable-producing areas in many Eastern states. Second, within these regions, the fact that some areas have suffered more from the severe outbreaks than other regions (again, likely owing to differences in demographics, density, and policy responses) means that the losses are highly concentrated; in fact, the bulk of the estimated losses occur in only a handful of counties. Yuma County, Arizona, a major producer of winter lettuce, is anticipated to endure significant losses (−\$13.3 million), followed by Imperial County, California (−\$7.2 million); Monterey County, California (−\$4.5 million); and Yakima County, Washington (−\$4.1 million).

Cumulating these losses at the state level reveals which fruit- and vegetable-producing parts of the country have been hardest hit. As the largest producer, and having been heavily affected by COVID-19, California stands to experience substantial losses in production (\$22 million in scenario 2), as serious outbreaks have occurred in many of the state's agricultural regions. While Arizona typically trails several other states in fruit and vegetable production, the severity of its current outbreak, and the fact that its outbreaks have been most severe in agricultural Yuma County, drive the finding that its losses are second only to California. In Washington, one of the country's largest fruit producers, Yakima County has been beset with one of the country's largest COVID-19 outbreaks (Hoang 2020); losses in commodities such as apples, cherries, and grapes place the state just behind California and Arizona. Florida is a major citrus-growing state; this, coupled with the severe outbreak in the state, means that production losses are also significant. Other states that grow specialty fruits (such as blueberries) and few vegetables tend to incur smaller losses.

Figure 2 Estimated production losses, by county [Color figure can be viewed at wileyonlinelibrary.com]



Conclusion

The COVID-19 epidemic is still unfolding, and one of its most significant ongoing effects has been its disruption to labor markets. Fruit and vegetable production relies heavily on labor and faces significant challenges arising from COVID-19-induced disruptions to its workforce in addition to the critical labor shortages it already faces. Compounding these challenges is the fact that many of the worst outbreaks have occurred in major fruit- and vegetable-producing areas, with the crowded conditions under which farm laborers live and work exacerbating the virus's rapid spread.

Our findings can be summarized as follows. Using county- and commodity-level data, we first estimate the output elasticity of labor demand for several major labor-intensive fruits and vegetables. Based on these estimates and current active COVID-19 infection rates by county, we then forecast the likely production losses across commodities and geographical regions from shocks to the farm labor supply under conservative and extreme scenarios. In both scenarios, we anticipate that disruptions to the labor force in fruit and vegetable production will cause millions of dollars in lost production, with the heaviest losses concentrated in large fruit- and vegetable-producing states such as California, Arizona, Washington, and others. These losses are incurred across several important commodities, including lettuce, apples, grapes, and strawberries, the production of which tends to be located in areas hit hard by the epidemic. As our county-level analysis of production effects shows, millions of dollars of losses are concentrated in only a handful of major fruit- and vegetable-producing counties.

Putting our findings in context, however, it is clear that the industry is not likely to be subject to widespread production losses even in our extreme scenario. Millions of dollars in losses for a multibillion-dollar industry are not trivial, but neither are they cataclysmic. The fact that a significant disruption to a sector already facing labor-supply challenges will have minimal effects in the aggregate speaks to the resilience of the sector and stands in contrast with industries such as meat processing that have been afflicted by significant production bottlenecks as a result of the pandemic.

While the relatively small industry-wide losses on their own are unlikely to have significant effects on US consumers, broader disruptions in food and agriculture—both domestically and abroad—suggest that our findings should not be considered in isolation. The Mead et al. (2020) reported in a recent bulletin that the food-at-home price index rose by 4.3% from March to June 2020, with across-the-board price increases in each subcategory of the index, including fruit and vegetables, and in spite of dramatically reduced demand from the food service sector. Further, disruptions to fruit and vegetable production in trading partners such as Mexico and the European Union are likely to be at least partly responsible for US fruit and vegetable imports from March to July 2020 declining by roughly \$300 million relative to the same period for 2019 (U.S. Census Bureau 2020). Beyond fresh-market effects, downstream food processing sectors are also likely to be adversely affected by the short supply of fruit and vegetables.

The federal government was swift in its reaction to outbreaks among workers in the meat processing sector, but protections for the large number of workers involved in fruit and vegetable production have been slow in coming. However, active measures by growers, processors, and government officials are likely to help mitigate many of the worst effects and are essential for

protecting the health and safety of workers in this vital part of the agricultural sector.

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